Fracture strength and bending of all-ceramic and fiber-reinforced composites in inlay-retained fixed partial dentures

Serkan Saridag, Atilla Gokhan Ozyesil, Gurel Pekkan

Department of Prosthodontics, Faculty of Dentistry, Kocaeli University, Kocaeli, Turkey
Department of Prosthodontics, Faculty of Dentistry, Selcuk University, Konya, Turkey
Department of Prosthodontics, Faculty of Dentistry, Dumlupinar University, Kutahya, Turkey

Final revision received 12 December 2011; accepted 26 March 2012
Available online 22 May 2012

Abstract  Background/purpose: In the most recent decade, the use of all-ceramic and fiber-reinforced composites as inlay-retained fixed partial dentures has increased. There are limited studies of comparisons of the mechanical strength and bending of these restorations. The aim of this in vitro study was to compare the fracture strength and the amount of bending in all-ceramic and fiber-reinforced composite inlay-retained fixed partial dentures.

Materials and methods: Forty mandibular premolars and 40 mandibular molars were collected. The specimens were randomly divided into four groups of 10 molars and premolars within each group, each with box-shaped proximal preparations. Two different all-ceramic systems (IPS e.max Press and ICE Zirkon) and two different fiber-reinforced composite systems (EverStick and Vectris) with a connector size of 16 mm² were used to restore prepared abutment teeth. After thermal cycling (5 and 55°C × 5000), a vertical force was loaded to the center of the inlay-retained fixed partial dentures at a crosshead speed of 0.5 mm/min. Failure types of specimens were examined with a stereomicroscope and radiography. Statistical analysis was performed using one-way analysis of variance (ANOVA) and Mann-Whitney-U tests (α = 0.05).

Results: Fracture strengths were significantly higher in the ICE Zirkon (1540 N) and EverStick specimens (1057 N) than in the Vectris (794 N) and IPS e.max Press specimens (606 N) (P < 0.001). The amount of bending was significantly greater in the EverStick (1.94 mm) and Vectris (1.87 mm) specimens than in the ICE Zirkon (1.07 mm) and IPS e.max Press specimens (1.18 mm) (P < 0.001).
Introduction

In current dental practice, the treatment philosophy is based on the least invasive approach, whereby intact tooth tissues are conserved as much as possible. The traditional method of molar replacement is either with a fixed partial denture (FPD) or an implant-retained crown. Irrespective of the type of FPD, the clinician uses a crown preparation that is a risk to pulp vitality and may lead to pulpal reactions in the long term. Approximately 63%–73% of the coronal tooth structure is removed when teeth are sent. Use of some types of ceramics is still limited in the posterior region for biological and economic reasons. The mechanical performance, superior strength, and fracture toughness of high-strength dental ceramics may have overcome this limitation. Recent progress in material production and processing technology is essential, especially in the posterior region. Therefore, proper selection of restorative materials is necessary, especially in the posterior region.

Materials and methods

Eighty freshly extracted intact and caries-free human teeth of similar size (40 mandibular molars and 40 mandibular premolars) were collected. The teeth were cleaned by curettage and stored in a saline solution at room temperature. Before the experiment, the roots of the teeth were curedtted and stored in a saline solution at room temperature. After the experiment, the roots of the teeth were covered with a 0.2 mm-thick layer of polyether material (Impregum Garant L Duosoft, 3M ESPE, Seefeld, Germany) to simulate the human periodontium. Each sample included a premolar and molar embedded 1.0 mm apical to the cementoenamel junction in an autopolymerizing acrylic resin block (Meliomént, Heraeus Kulzer, Hanau, Germany). The distance between the abutments was 11 mm, to simulate the human periodontium.

Conclusions: Zirconia-based ceramic inlay-retained fixed partial dentures demonstrated the highest fracture strength. The fiber-reinforced composite inlay-retained fixed partial dentures demonstrated higher bending values than did the all-ceramic inlay-retained fixed partial dentures.
represent the loss of a mandibular first molar. Artificial tooth mobility was evaluated in the horizontal and vertical directions using a periotest instrument (Periotest, Siemens AG, Bensheim, Germany). Periotest values of the embedded teeth were standardized at a value of < 7 to simulate the natural dentition.[18]

Specimens were randomly divided into four groups (n = 10) with proximal preparations on each abutment adjacent to the edentulous area. For molars, the isthmus in the box-shaped proximal preparation was 4 mm wide, 6 mm long, and 2 mm deep, and the proximal box extending 1.5 mm apical to the isthmus floor was 1.5 mm wide. The difference in the tooth preparation for the premolar was only in the isthmus length (4 mm) (Fig. 1). Tooth preparations were made by the same operator with the same sequence of specific diamond burs (Inlay Preparations Set 4261, Komet, Lemgo, Germany) and constant water cooling. To ensure standardized preparation of the abutments, a milling machine (Paraskop, Bego, Bremen, Germany) was used to evaluate the preparation dimensions.

Lithium-disilicate glass ceramic IRFPDs (IPS e.max Press, Ivoclar Vivadent AG) and zirconia ceramic IRFPDs (ICE Zirkon, Zirkonzahn GmbH) were fabricated according to the manufacturers’ instructions. The lithium-disilicate glass ceramic IRFPD frameworks were manufactured by a conventional press technique.[3] The veneering ceramic for the lithium-disilicate-based IRFPDs was its specific glass ceramic (IPS e.max Ceram, Ivoclar Vivadent AG). ICE Zirkon frameworks were milled in a “green” ceramic condition and sintered to the final dimensions (Fig. 2). The veneering ceramic for the zirconia-based IRFPDs was the glass ceramic of the same company (ICE Ceramik, Zirkonzahn). The glass-fiber frameworks (Vectris, Ivoclar Vivadent AG) and stick glass-fiber frameworks (EverStick, Stick Tech) were made using an indirect technique according to the manufacturers’ recommendations (Figs. 3, 4). In both groups, the pontics were built up layer by layer, with different composite materials (Fig. 5). The layering material for the EverStick framework was indirect resin composite (Solidex, Shofu, Ratingen, Germany), whereas the layering material for the Vectris framework was another indirect resin composite (Adora, Ivoclar Vivadent AG). The dimensions of the connector were 4 × 4 mm, to enhance an optimum mechanical stress distribution, provide mechanical retentive features, and allow fabrication of accurate inlay restorations, with good adaptation and strength of the restorative material.[7,19]

Zirconia-based specimens were etched for 180 seconds with a priming agent (Metal/Zirconia Primer, Ivoclar Vivadent AG). The interior surfaces of all specimens were silanated with porcelain primer (Monobond S, Ivoclar Vivadent AG) for 60 s and then air-dried. A bonding agent (Heliobond, Ivoclar Vivadent AG) was applied to the ceramic surfaces, air-dried for 3 seconds, and left under a light-resistant box. Before luting of the IRFPDs, the enamel portions of the preparations were etched for 30 seconds and the dentin surfaces of the teeth for 15 seconds with 37% phosphoric acid (Total Etch, Ivoclar Vivadent AG). Following this, all etchant gel was removed with water spray for 5 seconds. Excess moisture was removed leaving the dentin surface with a slightly glossy wet appearance. The Syntac Primer and Adhesive (Ivoclar Vivadent AG) were consecutively applied and thoroughly air-dried. Heliobond (Ivoclar Vivadent AG) was applied and blown to a thin layer. It was polymerized with the cementation material. The IRFPDs were adhesively luted using a dual polymerizing composite luting agent (Variolink II, Ivoclar Vivadent AG). Dual polymerizing resin cement (Variolink II base transparent, Ivoclar Vivadent AG) was mixed with its catalyst (Variolink II transparent high viscosity, Ivoclar Vivadent AG) in equal parts for 15 seconds and applied to the IRFPD bonding surface and cemented with finger pressure, and the specimen was exposed to polymerizing light from two opposite directions for 40 seconds each.
Specimens were stored for 24 hours in distilled water at 37°C, then thermocycled for 5000 cycles in two water baths at 5 and 55°C. The dwell time at each temperature was 30 seconds, and the transfer time from one bath to the other was 2 seconds. After thermal cycling, the IRFPDs were loaded until fracture occurred, using a universal testing machine (TSTM 02500, Elista, Istanbul, Turkey) with a crosshead speed of 0.5 mm/minute. A vertical force was applied to the central fossa of the pontic with a round-ended steel rod 5 mm in diameter. In order to reduce the local force peaks, 0.5 mm-thick tinfoil was inserted between the steel rod and pontic. The amount of bending (mm) was also evaluated by measuring the distance the test rod moved from the 10-Newton (N) preload to fracture.

Specimens were examined for the type of failure with a stereomicroscope (SZTP, Olympus, Tokyo, Japan) and radiography (Heliodent DS, Siemens, Munich, Germany). The statistical analyses consisted of a nonparametric one-way analysis of variance (ANOVA, Kruskal-Wallis) and a Mann-Whitney U-test, to determine differences between groups ($\alpha = 0.05$).

**Results**

The mean and standard deviations for fracture strength and bending amounts were recorded in N and mm, respectively, for the three groups (Table 1).

<table>
<thead>
<tr>
<th></th>
<th>Fracture strength Mean (SD) (N)</th>
<th>Bending Mean (SD) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPS e.max Press</td>
<td>606.20a (129.36)</td>
<td>1.077d (0.170)</td>
</tr>
<tr>
<td>ICE Zirkon</td>
<td>1539.82c (191.16)</td>
<td>1.189d (0.224)</td>
</tr>
<tr>
<td>EverStick</td>
<td>1056.90b (243.84)</td>
<td>1.941e (0.198)</td>
</tr>
<tr>
<td>Vectris</td>
<td>793.64a (157.31)</td>
<td>1.870e (0.192)</td>
</tr>
</tbody>
</table>

mm = millimeter; N = Newton; SD = standard deviation. Within the same column means with different uppercase superscript letters differ statistically according to Kruskal-Wallis and Mann Whitney U tests ($P < 0.001$).

For fracture strength, there were significant differences between all groups ($P < 0.001$) except between the IPS e.max Press (606 N) and Vectris (794 N) specimens. The highest median fracture resistance was recorded for ICE Zirkon specimens (1540 N). Significantly lower fracture results were determined for Vectris specimens (794 N) than EverStick specimens (1057 N). Additionally, the results showed that the bending amounts were significantly greater in the FRC groups than the all-ceramic groups ($P < 0.001$).

The IPS e.max Press specimens displayed equal numbers of failures in both connectors and retainer areas. The ICE Zirkon specimens predominantly demonstrated connector failure. In addition, only one ICE Zirkon specimen was observed to have adhesive failure (Fig. 6). The predominant fracture behavior of the FRC specimens was delamination of the veneering composite, whereas the framework stayed intact.

**Discussion**

New dental materials with new preparation designs have to be tested before they can be recommended for clinical use. It is not known what fracture resistance is required to achieve good long-term outcomes of IRFPDs in the molar region. Many authors investigated maximum bite forces during mastication, and mean values for the maximum bite force level varied (216 – 847 N). The highest bite force
was found in the first molar region. Körber and Ludwig summarized that posterior FPDs should be strong enough to withstand a load of 500 N. Additionally, cyclic fatigue loading caused by mastication can considerably weaken the fracture resistance of dental restorations. Under conditions of the oral environment, inherent flaws of restorative materials act as the origin of crack propagation which can grow to critical sizes. The endurance limit for fatigue cycling that can be applied to dental ceramics is approximately 50% of the maximal fracture strength. Therefore, it seems reasonable to assume that an initial fracture resistance of 1000 N should be required for a favorable clinical prognosis of posterior IRFPDs.

The preparation designs for partial-coverage restorations are not standardized, in contrast to those for complete-coverage restorations. Various preparation designs have been proposed such as grooves, tube- or box-shaped proximal preparations, retentive-slot preparations, use of a rest seat on the occlusal surface, long chamfers, and lingual tooth reduction. However, in most studies, the cavity design appears insufficient. Behr et al. conducted an in vitro study comparing tube-shaped and box-shaped preparation techniques for IRFPDs using the Vectris/Targis system (Ivoclar Vivadent AG). In their study, the frameworks were composed only of pontic prepreg fibers, and showed fracture strength values of 696 N (531 – 958 N) for box-shaped preparations and 722 N (665 – 818 N) for tube-shaped preparations. Results of the current study demonstrated that FRC IRFPDs with box-shaped preparation designs revealed mean fracture strengths of approximately 794 N for the Vectris and 1057 N for the EverStick groups. Zirconia-framework IRFPDs (ICE Zirkon 1540 N) had significantly higher fracture strength than other all-ceramic (606 N for IPS e.max Press) and FRCs. The results support the first hypothesis that all-ceramic IRFPDs have higher fracture strength and than FRCs. The zirconia frameworks of the IRFPDs were industrially manufactured from Y-TZP, the superior material characteristics of which were proven in various studies. These particles are densely sintered, resulting in a final microstructure in which voids, flaws, and cracks are reduced to a minimum. For this reason and because of the transformation-toughening mechanism, Y-TZP frameworks offer remarkable fracture strengths. Kılıçarslan et al. concluded that zirconia-framework IRFPDs exhibit the highest resistance to fracture compared to metal-ceramic and glass-ceramic ones. Failures of all-ceramic IRFPDs were always cohesive and were located at the connector areas that represent the weakest parts of the IRFPDs.

Several factors may effect fracture resistance of FPDs fabricated from glass-fiber-reinforced materials systems. In addition to the type of fibers used, their quantity, toughness, position, and type of impregnation may considerably influence the fracture resistance. Data from this study also showed that the difference in fracture strengths between the two FRC groups was statistically significant (P < 0.001). FRC IRFPDs made with EverStick had greater fracture strengths than FRC IRFPDs made with Vectris. While both of these materials use continuous, unidirectional E-glass fiber reinforcement, the method of fabrication differs. Fibers are usually impregnated with monomers, polymers, or a combination of both, in order to achieve good adhesion with the veneering composite resin. For the Vectris group, a prepreg of fibers in a dimethacrylate matrix is used to create the substructure. For the EverStick group, the prepreg of fibers is contained within a bi-phase matrix consisting of dimethacrylate and poly (methyl methacrylate) (PMMA) polymers. The PMMA matrix is highly viscous compared to the dimethacrylate system, hence improving both the handling properties and bonding properties of the FRC after it is polymerized. In this study, the different matrix compositions of FRCs may have affected the fracture strength values.

Fiber-reinforced materials have higher bending tendencies because of their lower moduli compared to all-ceramic materials. Therefore, the second hypothesis, that FRCs have higher bending than all-ceramic IRFPDs, was also accepted. In this study, data showed that the difference in bending amounts between the two FRC groups was not statistically significant (P > 0.05), although FRC IRFPDs made with glass-fiber-reinforced Vectris exhibited a lower bending amount than those made with EverStick.

Vallittu evaluated the survival rate of 29 resin-bonded glass-fiber-reinforced composite FPDs in a clinical study for periods of up to 42 months, and the Kaplan-Meier survival rate at 63 months was 75%. Three of the failed FPDs were rebonded or repaired in situ, producing a functional survival rate of 93% after rebonding or repair of the veneering composites. Van Heuman et al. evaluated 5-year survival of three-unit FRC fixed partial dentures in posterior and anterior areas. They found a success rate of 71% and survival rate of 78% after 5 years for posterior areas and a success rate of 45% and survival rate of 64% after 5 years for anterior areas. However, Behr et al. concluded in a clinical report that the veneering composites of FRC restorations need further improvement because of the increasing wear, discoloration, and fractures of the facings, and fiber exposure. Visually, the main weak point of FRC IRFPDs is the veneering material, as veneer fractures are initiated before debonding of the fibers under load. This finding is in accordance with Cho et al., who reported cracking and chipping of the veneering resin that was followed by adhesive failure between the veneering composite and fiber framework. For most specimens, the displaced fragment was not completely detached from the fiber framework. In the present study, the fracture analysis supported this statement.

This study attempted to simulate oral conditions, particularly in terms of simulating physiological tooth movement with a polyether coating. Despite wide variations present among human teeth, they were used in this study because the fracture strength is critically dependent on the elastic modulus of the abutment materials. Furthermore, it was demonstrated that abutment mobility is a decisive factor when evaluating fracture strength, and when a small amount of abutment rotation is allowed, failure is more likely. One limitation of this study was the non-inclusion of an artificial aging process, such as mechanical loading, which would have simulated its negative effects on fracture strength.

In conclusion, yttrium-oxide partially stabilized zirconia-based ceramic IRFPDs demonstrated the highest fracture strength compared to FRC IRFPDs and lithium-disilicate...
glass ceramic IRFPDs. FRC IRFPDs had higher bending values than all-ceramic IRFPDs. The predominant fracture behavior of the all-ceramic IRFPDs was in the connectors and retainer areas; however, FRC specimens exhibited delamination of the veneering composite.

Acknowledgments

The authors thank Associate Prof. Dr. Nilgün Öztürk for statistical assistance, Associate Prof. Dr. Ali Murat Sümüşl for scholarly advice, Associate Prof. Dr. Ali Murat Sümüşl for statistical assistance, and As Dental Konya, Den-tek A.S Izmir, and Anil Dental Izmir for materials and laboratory support.

References